

"SOME RECENT RESEARCH RELATED TO APPROACH PROBLEMS"

by

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I regret not being present here today to participate in this panel discussion on approach problems, but as this was not possible, I have attempted to summarize recent and current work at Ames Research Center related to the solution of some of these problems.

I am sure all of you here are familiar with the development picture. Aircraft are getting larger, and they tend to be shorter-coupled and of lower aspect ratio -- which results in sluggish response, reduced control power, and a requirement for a greater attitude change to achieve a given change in flight-path angle. When we combine these trends with our desire to achieve Category II and III minimums, to reduce approach noise, and at the same time improve our safety record, we are faced with a formidable problem.

What is NASA doing about this? It is our primary responsibility at NASA to anticipate the aircraft development picture and to provide research sufficiently in advance to remove insofar

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as possible operating problems from existing or new aircraft during the design phase. Unfortunately, this is not always possible. For example, the clearest definition of an approach problem is usually obtained after the problem is found to exist. Another limitation we face is that it is not possible for NASA to become involved in every current operating problem. Of necessity, we must be selective of those we put our effort on. Two problem areas currently receiving our attention which I shall discuss here relate to (1) methods of improving vertical flight-path control of large, sluggish airplanes, and (2) methods of reducing airplane noise during landing approach.

Direct-Lift Control. - During the past year and a half, we have conducted extensive simulator and flight investigations of the potential benefits and problems associated with the use of direct-lift control (DLC). By direct-lift control is generally meant the ability to modulate aircraft lift directly without changing the angle of attack of the wing. The delays imposed by rotating an aircraft to achieve a rate change in flight path would theoretically become unnecessary if such control were achieved directly through vertical thrust modulation or by direct control of wing lift. Recent work by the U.S. Navy at the Flight Test Center, Patuxent River, had shown the benefits which could be derived on an F8-U airplane during a carrier approach, but research related to transport-airplane operation was needed.

Several methods are possible to achieve this, but our initial work made use of upper wing spoilers which were already available on our Convair 990, thereby providing the opportunity for the evaluation of DLC on a large transport airplane. An initial study utilizing a piloted flight simulator was conducted using both ILS instrument and visual approaches, and was sufficiently encouraging to proceed to a flight phase. An initial validation of the simulation work was obtained using the Convair 990 speed-brake control, but this awkward arrangement was shortly replaced by a thumb controller on the control wheel, and by direct integration with the control column and the elevator, and even the throttle. Most of the evaluations were conducted at the least favorable aircraft center-of-gravity position, the aft limit. Under this condition, longitudinal control of the basic aircraft (without DLC) becomes much more difficult, and poor control system characteristics combine with the short-period dynamics to produce longitudinal control characteristics not unlike those anticipated for a large, sluggish aircraft of the future. Such characteristics tend to lead to overcontrolling in pitch as the pilot tends to force the aircraft response. Unless the pilot workload is increased and close attention paid to maintaining very tight control of attitude and flight path, pitch attitude is apt to wander, and it becomes difficult to achieve satisfactory performance, particularly under conditions of lower minimums, as represented by Category II operation. The results obtained with each of the three methods investigated

for utilizing DLC will be discussed next and followed with a summary of the Convair 990 DLC results.

Separate DLC Controller. - Use of a separate thumb controller for DLC definitely improved the ILS tracking below about 600 feet where sensitive glide slope error information was available. Very rapid correction of small ILS errors <sup>was</sup> ~~were~~ possible without noticeable change in aircraft attitude. Such use did not eliminate the necessity for pitch-attitude changes, however, in obtaining initial stabilization on the glide path, or for rotation of the airplane to achieve a satisfactory landing attitude. While this mode was the one considered the most favorable for the F8-U in a carrier approach, the additional procedures and control requirements were generally not considered acceptable for transport operation. The pilot still was required to coordinate his throttle, direct-lift control, and pitch attitude throughout the approach, flare, and touchdown. Approaches made using the autopilot coupler confirmed that if attitude were stabilized, the use of direct-lift control was much easier and much of the confusion was eliminated. The potential benefits of direct-lift control were verified, however, and it was indicated that  $\pm 0.15$  "g" capability was sufficient to provide a significantly improved control during the final portion of the approach, and had potential benefit during flare and in control of touchdown point.

Interconnect Modes. - A large number of interconnect modes utilizing various gains were investigated in conjunction with the normal elevator control. With this application, the benefits were primarily the quickened vertical response accompanying conventional pitch attitude changes rather than the direct flight-path modulation without attitude change. In this manner, normal piloting procedures and techniques were directly applicable, and the complication of an additional control was not involved. In addition to the improved flight path control below about 600 feet where sensitive glide slope error information is available either from the ILS or visual cues, this method of DLC control was also appreciated during flare and touchdown as it provided distinctly improved control of sink rate and touchdown precision. Without going into the effects and implications of the various interconnect and gain modes investigated, it was concluded that the control column (elevator) interconnect mode was most effective in improving flight path angle response. Quickening of the pitch-attitude response by tailoring of the pitching moments associated with DLC modulation was also found to be desirable and effective.

Throttle Interconnect Mode. - Direct-lift control derived from throttle movement was also investigated and was considered useful in improving touchdown accuracy. The immediate lift loss achievable with a throttle cut enabled positive control of touchdown similar to that obtained with propeller aircraft. No improvement in glide slope tracking, however, was noted. A combination of DLC interconnects with the throttle as well as the elevator

control column appeared to offer considerable potential, but potential conflicts arising from multiple functions for DLC need further consideration.

Summary of Conclusions. - The potential benefits and applications of DLC to transport airplanes as derived from a combined simulator and flight program on a Convair 990 airplane may be summarized as follows:

1. DLC can provide improved short-period pitch and flight path response for sluggish airplanes.
2. DLC can provide some flight angle correction capability without an attitude change.
3. The DLC advantages associated with obtaining flight path angle changes without an attitude change appear to require some form of autostabilization in pitch to realize maximum effectiveness.
4. The DLC maneuvering ~~h~~ capability represented by  $\pm 0.15$  "g" on the Convair 990 was sufficient to provide significant improvement.
5. The benefits are generally confined to the final part of the approach and during flare and touchdown. With very sluggish airplanes, however, the benefits can be more extensive.
6. Multiple forms of integration in the airplane appear to provide additive benefits, but requires more detailed study.

Approach Noise Reduction. - In addition to the desirability of improved flight-path control under reduced-minimum weather conditions, an acute problem which is of necessity receiving increasing attention is that of reducing noise during both take-off and landing operations. To date, the direct approach to the noise problem has been the modification of takeoff and landing procedures and techniques. There are, of course, definite limits to how far one can progress in this direction without providing the pilot with improved tools with which to do the job. One technique for reducing the noise has been the possibility of using steeper approach angles. This has been investigated extensively by Langley Research Center and the conclusions reached by that investigation and reported to this Seminar last year and in NASA TND-4044 are pertinent. I quote, "This progress report indicates that steepened approach paths are a feasible method of noise reduction but considerably more study and qualification of the task will be needed before it could be considered operational. As viewed at this time, the major obstacles are in the information provided the pilot, the method of flight control, and the problem of providing paths equivalent to those provided by the research radar equipment used in the tests." It is, therefore, important that we consider the problems of steeper approach paths in our research just as we do requirements to fly to lower and lower ceilings. Such tasks provide the

stimulant for research and development effort to improve control and guidance, increase the pilot-airplane capability, and, hopefully, contribute to increased safety.

I would now like to summarize the initial results of a rather extensive NASA program which is primarily aimed at the approach noise reduction problem, but brings together many facets of the total approach problem. The Langley study indicated, for example, that unless a steepened flight path is accompanied by reduced power, the noise reduction will be considerably less than the maximum obtainable. This problem is, as we all know, constrained by the engine response characteristics at low thrust conditions. A portion of the Ames program is related to the development of an advanced flap design which will enable maintenance of high lift at reduced power settings, as well as providing an alternate DLC capability to that provided by spoilers. The details of the high-lift flap research program to provide aerodynamic characteristics more suited to noise abatement approaches is beyond the scope of this paper.

The first phase of the program was completed during this past summer and made extensive use of both ground and airborne simulation. The flight portion of the program involves the Boeing 707 prototype, the 367-80 variable-stability aircraft. This program makes use of the unique simulation capabilities of the aircraft by extending the direct-lift control work done with the Convair 990 and for simulating advanced flap designs under study, as well as the particular design planned for later installation and flight test on the -80 airplane. In addition, it provides



a capability for the introduction of future aircraft aerodynamic characteristics, as well as simulation of various methods of control, both manual and automatic. The investigation of steeper approaches with improved, precise control methods for longitudinal flight-path control are possible. The longitudinal stability can be augmented to provide pitch response characteristics more to the pilot's liking, and various forms of flight-path-control augmentation can be provided.

Results to date obtained from considerable simulation and from 30 hours of actual flight evaluation are preliminary and have primarily established the ground work for a subsequent flight phase using a research flap now being fabricated. A specific objective of this preliminary phase was to determine some of the characteristics of a direct-lift control system that could aid the pilot in the performance of noise abatement approaches and to evaluate both on ground-based and in-flight simulation the use of DLC in steep and segmented landing approaches. The variable-stability Boeing 367-80 airplane was used to simulate a large jet transport using a relatively low approach speed that might be attained with advanced flap configurations. The variable stability features of the -80 enabled simulation of more refined DLC systems incorporating, for example, optimized trim and pitching moment characteristics. The results to date have enabled more definitive conclusions to be drawn with respect to acceptability of steep approaches, but are not in conflict with the results presented by the Langley study.

Results and Discussion. - Results from the initial phase of the -80 program indicate the methods required to improve acceptability of steep approaches. These are, (1) reduced sink rate near the ground, (2) provide some improvement in flight path control, (3) reduce pilot work load, and (4) improve guidance display information. As might be anticipated, it was demonstrated that reduction in approach speed which led to reduced rates of descent did, in fact, enable acceptance of steeper approach angles; for example, the rate of descent at 115 knots on a 4-degree approach is the same as a 3-degree approach at 140 knots. On the other hand, very large reductions in the approach speed would be required for the full 6-degree approaches needed to obtain the desired reduction in noise. Approach speeds much lower than 115 knots are usually associated with higher drag, and, therefore, requirements for higher engine power to achieve the so-called STOL or powered-lift operation. From the preliminary flight tests, 900-feet per minute was about the maximum considered acceptable to research pilots even when provided with some augmentation and improvement in flight path control from the DLC. In particular, autothrottle was considered a requirement in reducing the pilot's work load.

The use of DLC in the steep approaches was appreciated by the pilots primarily during flare and touchdown although it was generally concluded that the DLC benefits outlined by the Convair 990 program were present in this program. Benefits that might

be associated with large flight-path angle changes as from a 6-degree-to-touchdown or in a segmented approach were relatively small and were appreciated primarily as increased short-period response. The addition of autothrottle was of significant assistance to the pilot in his flight path control. Besides simplifying the intercept mode, the autothrottle, when used with direct-lift control, gave the pilot the ability to make larger rapid flight-path angle changes.

With steeper approach paths, the round-out or transition to a shallow segment dictated a requirement for an improved flight director. A parallel research program is, therefore, currently underway to investigate and modify the flight-director logic so that problems introduced by lack of adequate information during this phase of a steep approach are eliminated.

There was no question but that steep approaches were more demanding of the pilot and require reduction in pilot work load to be acceptable for routine operation. In addition to the requirement for autothrottle, there was noted a distinct need for the pilot to monitor the situation, to have continuous how-goes-it information, and to be able to think ahead. It was concluded that further reductions in pilot workload would be required and would most likely come from improved handling qualities based on (a) improved autopilot or augmentation systems, (b) improved information display (precise guidance plus situation information) and (c) simplified operational procedures.

Concluding Remarks. - In summary, then, the problems that limit use of steep approaches for noise abatement are (1) high sink rate near the ground, (2) high pilot work load in the approach, (3) inadequate guidance and display information, and (4) flight path control problems. Noise reductions arising from increased approach angles which can be achieved only by reduced approach speed with high-lift devices appear to be small. Combinations of reduced approach speeds and non-linear flight profiles can reduce rates of descent to acceptable levels, but adequate guidance and display information and flight path control must be developed. Finally, the requirement for noise abatement approaches has further stimulated NASA research in complex approach problems which are related to the achievement of Category II and III operation.